Section 22 New Hampshire

Recreational Carrying Capacity and Application to Lake Management

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RECREATIONAL CARRYING CAPACITY AND APPLICATION TO LAKE MANAGEMENT

prepared for
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INTRODUCTION

STUDY AUTHORITY

This study was conducted by the New England Division of the U.S. Army Corps of Engineers at the request of the New Hampshire Office of State Planning. Authority for this study is contained in Section 22, Public Law 93-251 as amended "Planning Assistance to States" which authorizes cooperation with the states in preparation of plans for the development, utilization, and conservation of water and related resources.

STUDY PURPOSE

This report is intended to provide New Hampshire water resource planners with a general understanding of the recreational carrying capacity concept as well as related issues including the management of lake resources for recreation. The New Hampshire Office of State Planning is currently developing a lake management plan for Squam Lake.

STUDY SCOPE

In recent decades participation in water based recreational activities has dramatically increased in the United States. As lakes have become more heavily utilized, concerns over issues such as water safety, the "quality" of the recreational experience, and the potential adverse impacts of recreation on lake ecosystems have become more pronounced.

The concept of "recreational carrying capacity" has proved to be a useful management tool for dealing with questions of overuse in a variety of recreational settings. This report is intended to review the carrying capacity concept, and its application to lake based recreational settings. Also provided is a discussion of lake management techniques to enhance carrying capacity, and a summary of the technical literature concerning the environmental affects of recreation on lakes. Finally, the implications of this work to lake management in the State of New Hampshire are briefly discussed.

THE RECREATIONAL LAKE CARRYING CAPACITY CONCEPT

Recreational carrying capacity is defined as the level of recreational use an area can sustain before an unacceptable decline in the quality of the recreational experience or natural resources occurs (Pigram, 1983). The concept is a highly subjective one. In contemporary terms, carrying capacity is generally considered to be a range of values derived within the context of specific management objectives and standards (Shelby and Heberlein, 1986).

Several components of recreational carrying capacity are recognized. These include "physical", "economic", "ecological", and "social" carrying capacity (Pigram, 1983). Each of these components is discussed in detail below. Social carrying capacity is generally regarded to be the key limiting factor in most recreational settings.

PHYSICAL CARRYING CAPACITY

Physical carrying capacity is concerned with the maximum number of people (or boats, activities) that can be accommodated by a recreational resource. The concept is generally regarded to encompass absolute space requirements (i.e. the minimum space required for swimmers on a beach), safety related concerns (i.e. the number of boats that can safely operate on a lake), and the availability of support facilities (e.g. parking lots, boat ramps, restrooms). The latter is sometimes referred to as "Facilities Capacity". Physical carrying capacity is exceeded when use levels are greater than those at which recreational activities can occur in a safe and efficient manner. Although physical carrying capacity is sometimes equated with recreational "space standards", the latter may be frequently based on factors other than absolute space requirements, and safety.

ECONOMIC CARRYING CAPACITY

Economic carrying capacity refers to the level of activity above which recreation has an unacceptable economic impact on other resources. The concept is applicable in situations where a recreational resource is simultaneously utilized for a number of other purposes (i.e. water supply, logging, commercial fisheries). Economic carrying capacity would be exceeded, for example, at a water supply reservoir, if the added operation and maintenance costs associated with recreational activities exceeded benefits derived from recreation.

SOCIAL CARRYING CAPACITY

Social carrying capacity is concerned with the impact of user density on the "quality" of the recreational experience. Pigram (1983) defined it as:

> "... the maximum level of recreational use in terms of numbers of activities, above which there is a decline in the quality of the recreational experience from the point of view of the recreation participant."

A more succinct working definition of social carrying capacity was provided by Shelby and Heberlein (1986):

> "The level of use beyond which social impacts exceed acceptable levels specified by evaluative standards"

Social impacts are defined in terms of the number, type, and location of encounters recreationists experience with other individuals or groups (e.g. the number of motorboats encountered per day by canoeists in a semi-wilderness lake). Use levels are evaluated in terms of some measure of recreational quality that is well correlated with user density. Proposed measures of recreational quality include: 1) user satisfaction, 2) perceived crowding, and 3) contact preference standards.

Social carrying capacity has frequently been evaluated in terms of user satisfaction (i.e. how "good" a person feels about a recreational experience). Although intuitively one would expect a strong negative correlation between satisfaction and user density for many recreational activities (Figure 1), most studies have failed to establish this relationship (Shelby and Heberlein, 1986; Vaske et al., 1983; Graefe et al., 1984). Because measures of satisfaction seem to be independent of user density, the concept appears to have little utility as a measure of recreational quality in carrying capacity studies. Measures of satisfaction based on user surveys may be a poor measure of recreational quality because people are able to freely choose their recreational settings. Those individuals who are sensitive to high user densities may simply avoid using a heavily used recreational resource. Remaining individuals may be more tolerant of higher user densities or adjust their expectations to compensate for the situation.

Social carrying capacity has also frequently been evaluated in terms of "perceived crowding" (see Shelby and Heberlein, 1986). Perceived crowding can be defined as "a negative evaluation of a certain density or number of encounters in a particular setting". Perceived crowding can be assessed simply by determining the percentage of individuals who feel crowded. Based on a number of studies, Shelby and Heberlein (1986) proposed that social carrying capacity is probably exceeded if more than two-thirds of users feel crowded. If fewer than one-third of individuals feel crowded, an area was safely assumed to be below carrying capacity.

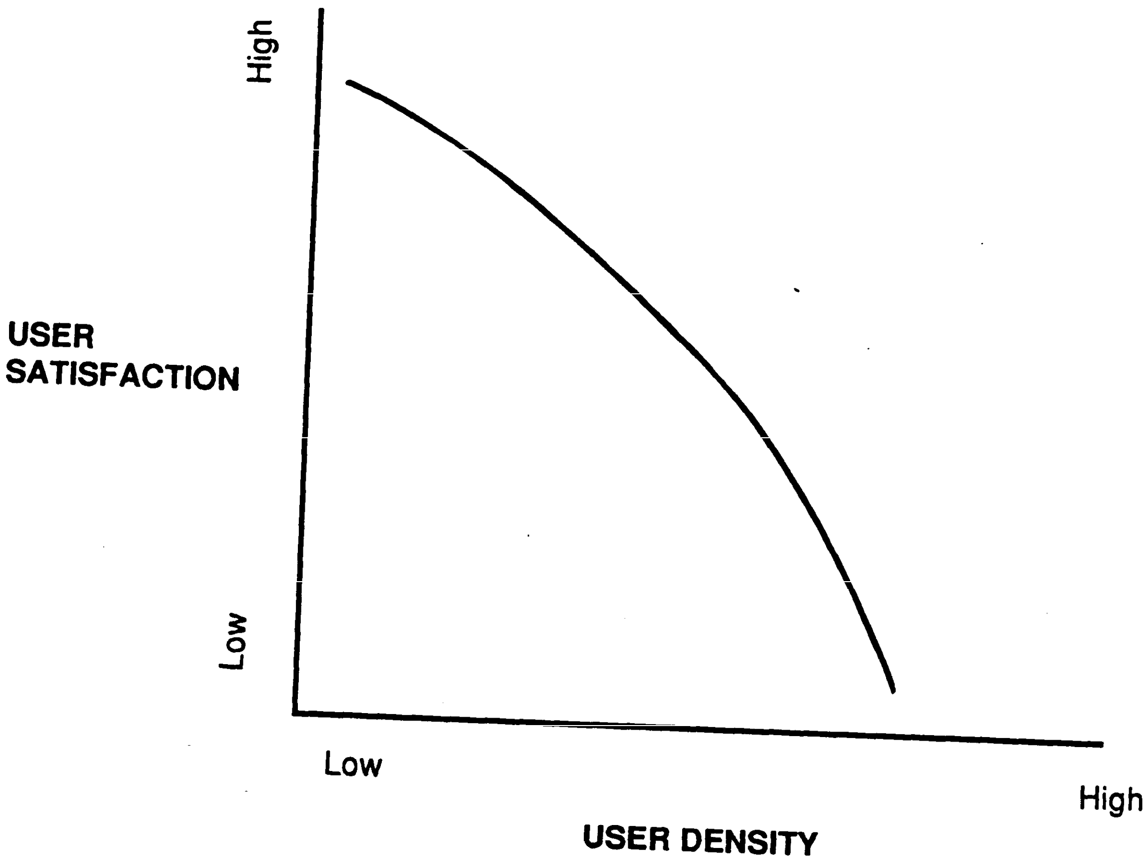


Figure 1: Relationship between user satisfaction and user density in recreational settings (after Pilgram, 1983).

Although perceived crowding is thought to be a more useful measure of recreational quality than user satisfaction, it is often poorly correlated with use levels (see Vaske et al., 1983) and may also be of limited utility in carrying capacity studies.

A third technique for evaluating impacts involves the establishment of social norms which define the appropriate number of encounters in a particular recreational setting (Shelby and Heberlein, 1986). These standards can be expressed by encounter preference curves (Figure 2) which establish the tolerable range of encounters. Social carrying capacity can be defined as the maximum level of use at which encounter levels are within the tolerable range. Actual levels of encounters from field reports can be compared to encounter preference curves to determine if usage exceeds carrying capacity. Although this technique has not been widely applied, it may be more useful as a a measure of recreational quality than either satisfaction or perceived crowding.

ECOLOGICAL CARRYING CAPACITY

Ecological carrying capacity is concerned with the impact of recreational activities on natural resources. The concept involves issues related to both the sustainable use of recreational resources and human perceptions of resource quality. Contemporary definitions include:

> "The level of use of a recreation resource beyond which irreversible deterioration takes place or degradation of the physical environment makes the resource no longer suitable or attractive for that recreational use." (U.S. Army Corps of Engineers, 1980)

> "... the maximum level of recreational use in terms of numbers and activities that can be accommodated by an area or an ecosystem before an unacceptable or irreversible decline in ecosystem values occurs." (Pigram, 1983)

Ecological carrying capacity is exceeded when a recreational resource is stressed to the extent that preexisting environmental conditions cannot be maintained by natural processes, or when the resource is no longer perceived to be acceptable by users.

Various problems arise when attempting to quantify ecological carrying capacity (Pigram, 1983; Sowman, 1987). Ecological systems are highly variable, and major difficulties arise when attempting to determine what constitutes an "unacceptable or irreversible" decline in ecosystem integrity. Furthermore it is often very difficult to establish a clear cause and effect relationship between the level of use and environmental impacts.

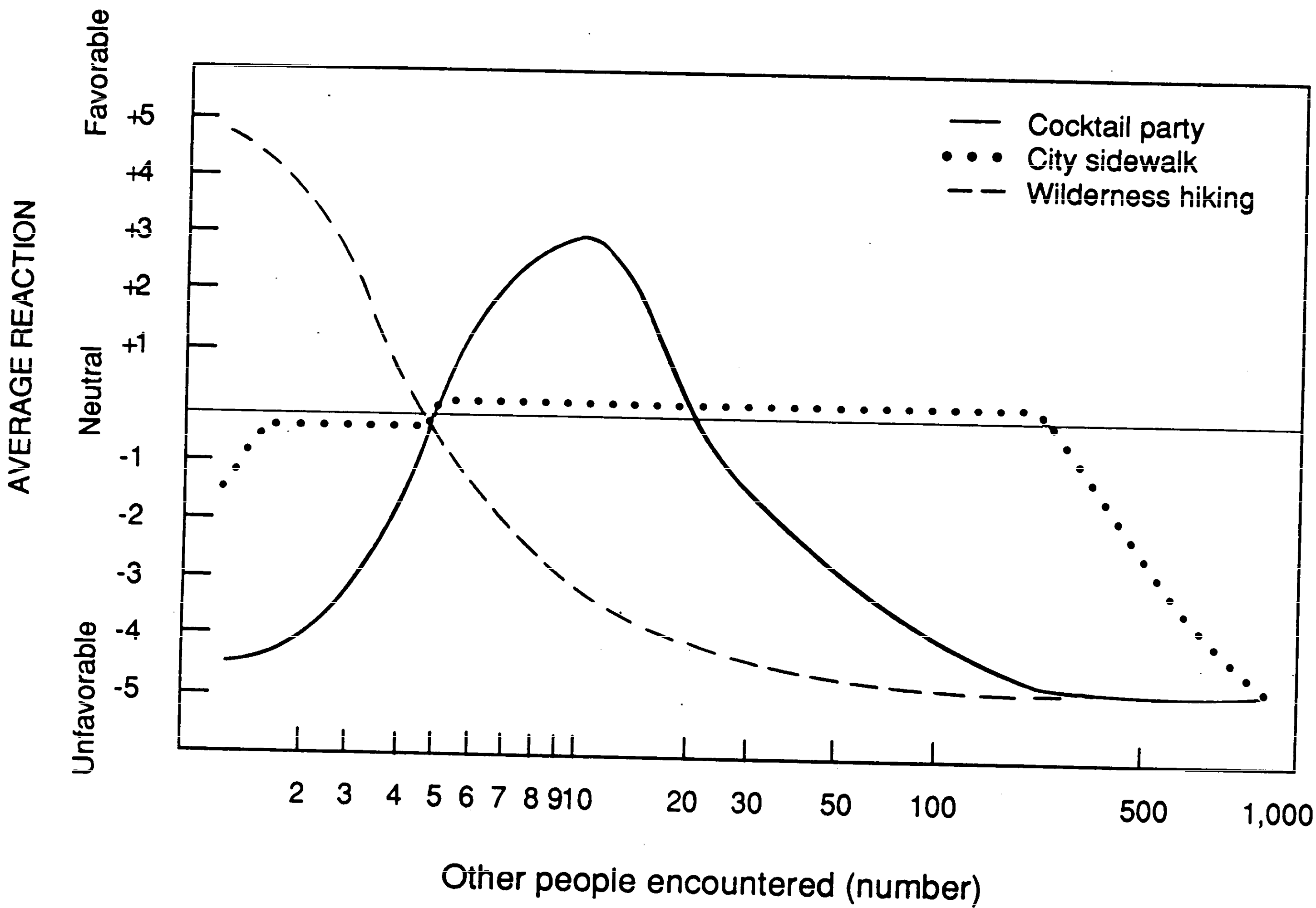


FIGURE 2: User preference curves (from Shelby and Heberlein, 1986).

Difficulties are also encountered because the ecological impact of a particular recreational activity can vary. For example the impact of fisherman and boaters on water fowl may only be significant for certain critical periods during the nesting season.

Lakes also differ in sensitivity to recreational impacts. For example a small increase in nutrient input may have a measurable impact on the productivity of oligotrophic lakes, but no discernible affect on nutrient rich eutrophic lakes.

Ultimately, the determination of ecological carrying capacity is a subjective decision which should be based on sound ecological principles, a thorough knowledge of the relevant literature, and management objectives.

RELATIVE IMPORTANCE OF CARRYING CAPACITY COMPONENTS

Although in some recreational settings physical, economic, or ecological constraints may limit recreational opportunities, social carrying capacity is likely to be the limiting factor in most instances (Shelby and Heberlein, 1986). In situations where social or ecological carrying capacity is exceeded, the manipulation of physical carrying capacity by limiting the availability of support facilities (e,g. parking lot spaces), can be a useful management technique for meeting carrying capacity guidelines.

RECREATIONAL LAKE CARRYING CAPACITY STUDIES

Various approaches have been employed to evaluate the recreational carrying capacity of lakes and reservoirs. Early studies relied largely on the establishment of rather arbitrary "space standards". In recent years studies have become more sophisticated, but remain constrained by the subjective nature of the carrying capacity concept, the complexity of lake based recreational systems, and problems with methodology. Ultimately carrying capacity estimates rely on management objectives and the needs and desires of recreationists, both of which can vary between lakes, and over time at the same lake.

The following section describes a variety of approaches that have been used to address lake carrying capacity concerns. Also presented is a general approach for determining recreational carrying capacity that may be useful in lake-based recreational settings. Previous reviews of lake carrying capacity studies include those of Jaakson et al. (1976), Hammon (1974), and Ashton (1971).

SPACE STANDARDS

Numerous early studies provide "space standards" for boating (Table 1). Estimates are largely based on safety concerns, though in some cases user satisfaction, and other management objectives are also taken into account. Estimates for any particular type of boating vary widely, and should be viewed only as general guidelines. There is general agreement, however, that water skiing and power boating require more water surface area than other types of boating.

Several factors preclude the development of uniform space standards for boating. Most importantly is the wide variation between lakes in terms of size, depth, shoreline development, and other morphological parameters. For example, a lake with many inlets and bays is likely to have greater carrying capacity than a circular lake with the same surface area. Space standards also fail to take into account potential conflicts between different types of boating and other recreational activities. Regulations may also impact space standards. For example, speed limits could substantially lower the space requirements of high speed power boating.

Space standards are also available for swimming beaches (Fogg, 1981; U.S. Bureau of Outdoor Recreation, 1970). Standards vary widely. Those presented by Fogg (1981) propose 8 - 20 persons per foot of shoreline for "low" and "high" density beaches, respectively. Space standards, including water and beach area, range from 75 (high density) to 150 (low density) square feet per person.

OTHER STUDIES

Ashton and Chubb (1972) attempted to establish the social carrying capacity of several heavily used Michigan lakes using regression models to relate use levels to user satisfaction. An arbitrary user satisfaction level was set as a standard to define carrying capacity. User satisfaction

Table 1
Boating Space Standards
(Acres per boat)

Authority[a]	General Standard	Non-Power	Power (unspec.)	Power (< 10 hp.)	Power (unlimit.)	Sailing	Water Skiing	Fishing
Allegheny Nat. For. (3)		1		5		1	20	1
Bur. Out. Recr. (1977)				2–10	3–18		7–20	
Calif. Recr. Comm (2)	1							
Corps of Engineers (1)	1							
Fogg (1981)		0.5		0.5	3	0.25	3	0.2[b] 0.5[c]
Grt. Lks. Basn. Comm. (1975)			10					2
Jaakson (1984)		0.33				1.25		
Louis. Park Recr. Comm. (1)			20				40	8
Manitoba (3)	50							
Mn. Dept. Nat. Res. (3)	10							
New York State (1978)		1	6–8			6–8	15–20	
New Hampshire (1985)		1.5			8.8			
Ohio Dept. Nat. Res. (2)				5.5	7.5			
Ontario Min. Hsg (3)	10							
Sirles (3)	0.8–1.8							
Soil Conserv. Ser. (1)			3			3	5	0.2[b] 0.35[c]
Sowman and Fuggle (1987)			5				20–40	1.2–10
Tichacek (3)		1		10–20		2	40	8
Wisc. Out. Rec. Plan. (1)			20				20–40	8
Wisc. Dept. Nat. Res. (2)	20							

a See the following for complete citations
(1) Bur. Out. Rec. (1970)
(2) Eberwein (1984)
(3) Barstad and Karasov (1987)
b anchored fishing
c trolling fishing.

was estimated for both boaters and waterfront property owners by utilizing interviews and self-administered questionnaires. Use levels were determined by calculating a "space consumption index" based on boat densities and on estimates of the water surface area consumed by various activities. Data on usage was obtained at frequent (1 hour) intervals from aerial photographs. Although Ashton and Chubb (1972) obtained carrying capacity estimates, their values are highly suspect because regression models explained little of the variability between use levels and boater satisfaction.

The methods employed by Ashton and Chubb (1972) were refined and further evaluated in studies of another Michigan lake by Rittenger (1976). This study failed to find a significant correlation between use levels and user satisfaction, and was thus unable to provide an estimate of social carrying capacity. The failure to find a significant relationship between use level and user satisfaction was attributed to problems associated with the study design, aerial photography, aerial photo interpretation, and data collection using interviews.

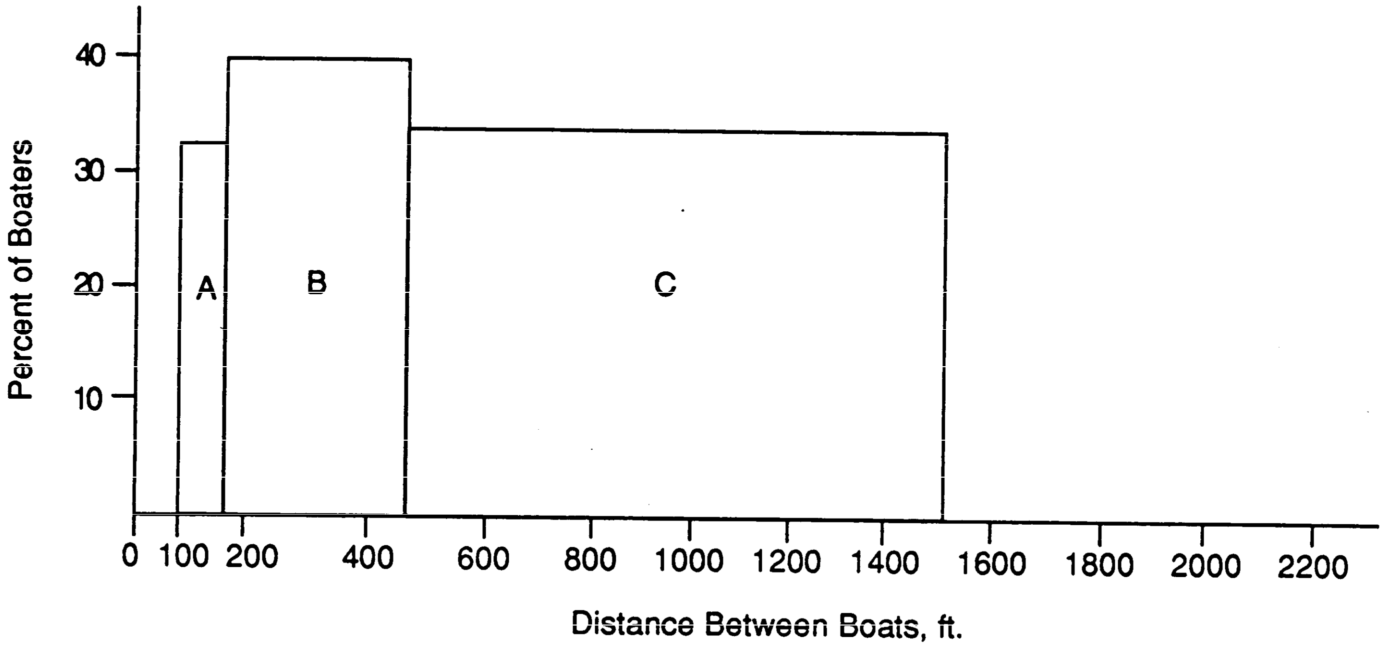
Overall, because user satisfaction is generally not correlated with use levels, the approach developed by Ashton and Chubb (1972) to determine lake carrying capacity probably has little utility.

An alternative method of determining lake carrying capacity was developed by the U.S. Army Corps of Engineers (1980). This system bases social carrying capacity estimates on "user preference distributions" (Figure 3). Preference distributions define the range of distances that individuals prefer to be from other recreationists. General preference distributions are tailored to individual situations by adjusting for various social and environmental factors ("social capacity factors"). Once distance guidelines are determined for a specific site, they can easily be converted to surface area guidelines (i.e. "space standards"), and compared to existing use levels. Existing use levels can be determined from direct observations, aerial photography, and boat launch records.

The Corps (1980) study and accompanying technical report provides detailed information concerning the application of this technique. Included are user preference distributions and social capacity factor values for a variety of other recreational activities. Values are based on surveys of over 2000 users at various Corps projects across the country. Although this technique appears promising, its utility has apparently not been further evaluated. As is the case with other methods, it may be of only limited utility in complex situations where conflicts between different types of recreational activities exist.

Klar <u>et</u> <u>al</u>. (1983) developed a complex mathematical model to aid in development of a recreation management plan for the Quabbin Reservoir in Massachusetts. The model integrated a variety of economic, environmental, and social factors to determine an optimal mix of recreational activities for the reservoir (Figure 4). In this study recreational carrying

User Preference Distribution



Social Capacity Factors Table

Site Characteristics	Variance	User Characteristics		Variance
Type of Area/Boat		Number of Other Activities		
Power	-35	<3	(48%)	+36
Nonpower	+156	>3	(52%)	-65
		Experience		
		None/Little	(25%)	+60
		Some	(22%)	-10
		Much	(53%)	-25
		Travel Time		
		<30 min	(39%)	-40
		>30 min	(61%)	+25
		Age		
		<26	(22%)	-35
		26-55	(70%)	+10
		>56	(8%)	0
		Group Size		
		1-2	(17%)	-20
		>2	(83%)	+ 5

Figure 3: U.S. Army Corps of Engineers (1980) user preference distribution for boating.

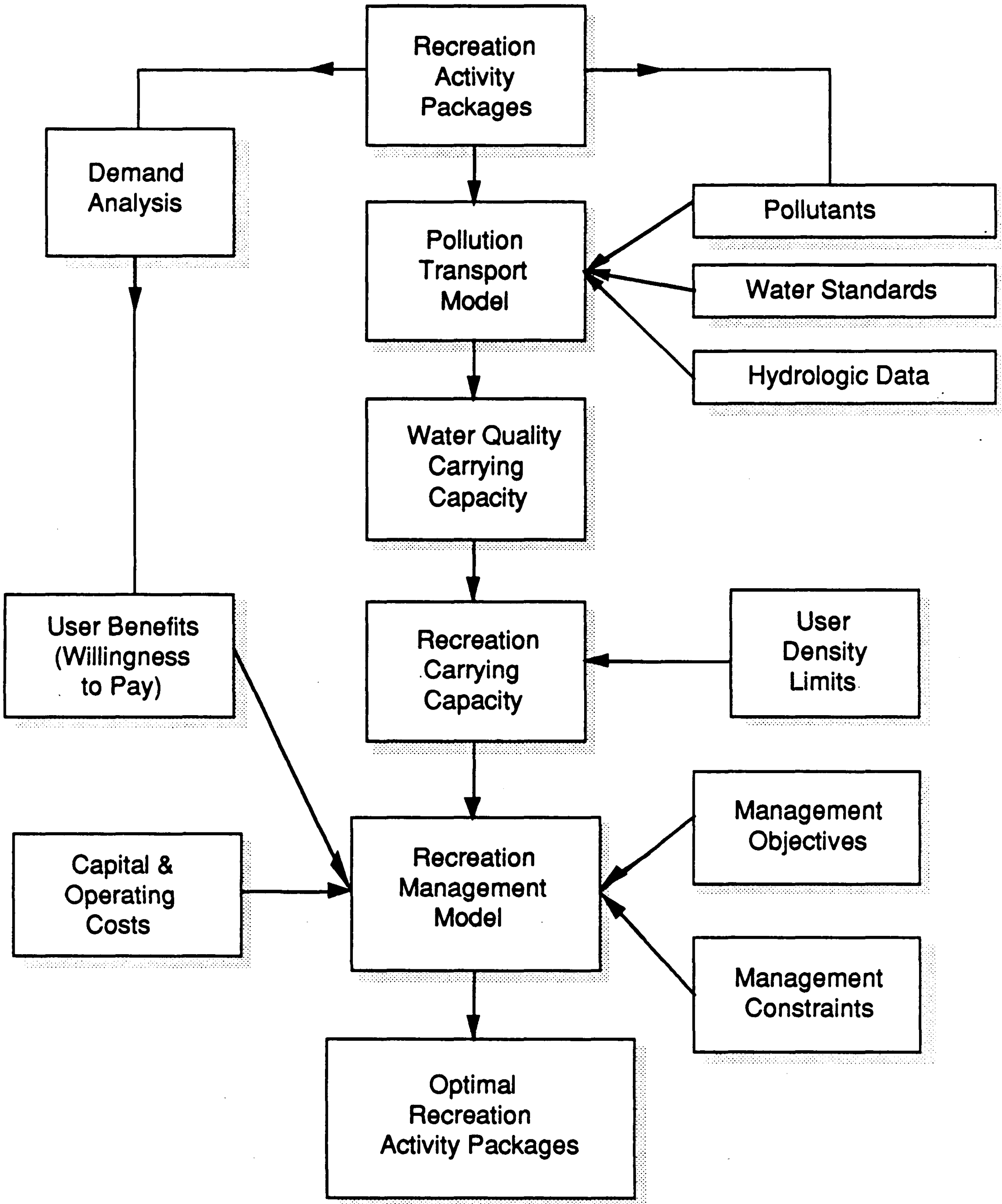


Figure 4: Model for determining the optimal mix of recreational activities on a water supply reservoir (from Klar et al.,1983).

capacity was evaluated based on water quality constraints and user density standards derived from Corps (1980) user preference distances.

Because algal bioassay studies suggested that the reservoir might be quite sensitive to phosphorus loading, the study concluded that no additional nutrient loading from increased recreation was tolerable. This ecological constraint was mitigated, however, by specifying that sewage retaining vaults would be placed at each recreational site to essentially eliminate potential phosphorus loading from human wastes. Furthermore, low user densities were recommended to minimize potential nutrient loading resulting from soil erosion. Costs associated with mitigating for environmental constraints were included in the economic analysis used to determine the optimum mix of recreational activities in the reservoir.

The Corps of Engineers (1983) conducted a study of a Pennsylvania lake to determine boating use patterns and density, and boater perceptions of recreational quality during peak use periods (two summer weekends and two holidays). The study relied on aerial photographs to establish boat use densities and distributions, and interviews to determine perceived crowding.

Aerial photographs indicated that user densities varied substantially within the lake, and between days, and averaged about 25 acres per boat. Localized areas of congestion were identified.

User surveys indicated that during periods of peak use, conditions on the lake were sufficiently "crowded" to alter the boating behavior of some users. Some boaters refrained from using the lake entirely, or for part of the day. Others avoided certain parts of the lake, or avoided certain activities (i.e. water skiing). Dock holders were more likely to refrain from using the lake because of crowding than day users or other boaters. Nearly two-thirds of dock holders indicated that they would increase their boating activity if the lake was less crowded.

Jaakson (1984) provides a case study of recreational planning for a small, heavily utilized, urban lake in Canada. Key aspects of the planning process were the establishment of carrying capacity limits, water use zoning, and the application of a decision making technique to resolve disputes between various governmental agencies involved in formulating the lake management plan. Carrying capacity estimates and space standards for sailboats and muscle-powered craft were based on detailed observations of boating patterns on the lake, and the subjective opinions of sailors.

Sowman (1987) provided a framework for determining recreational carrying capacity (Figure 5), and applied the technique to an enclosed South African estuary (Sowman and Fuggle, 1987). The major physical, ecological, and social constraints associated with further development of the estuary were identified based on information obtained

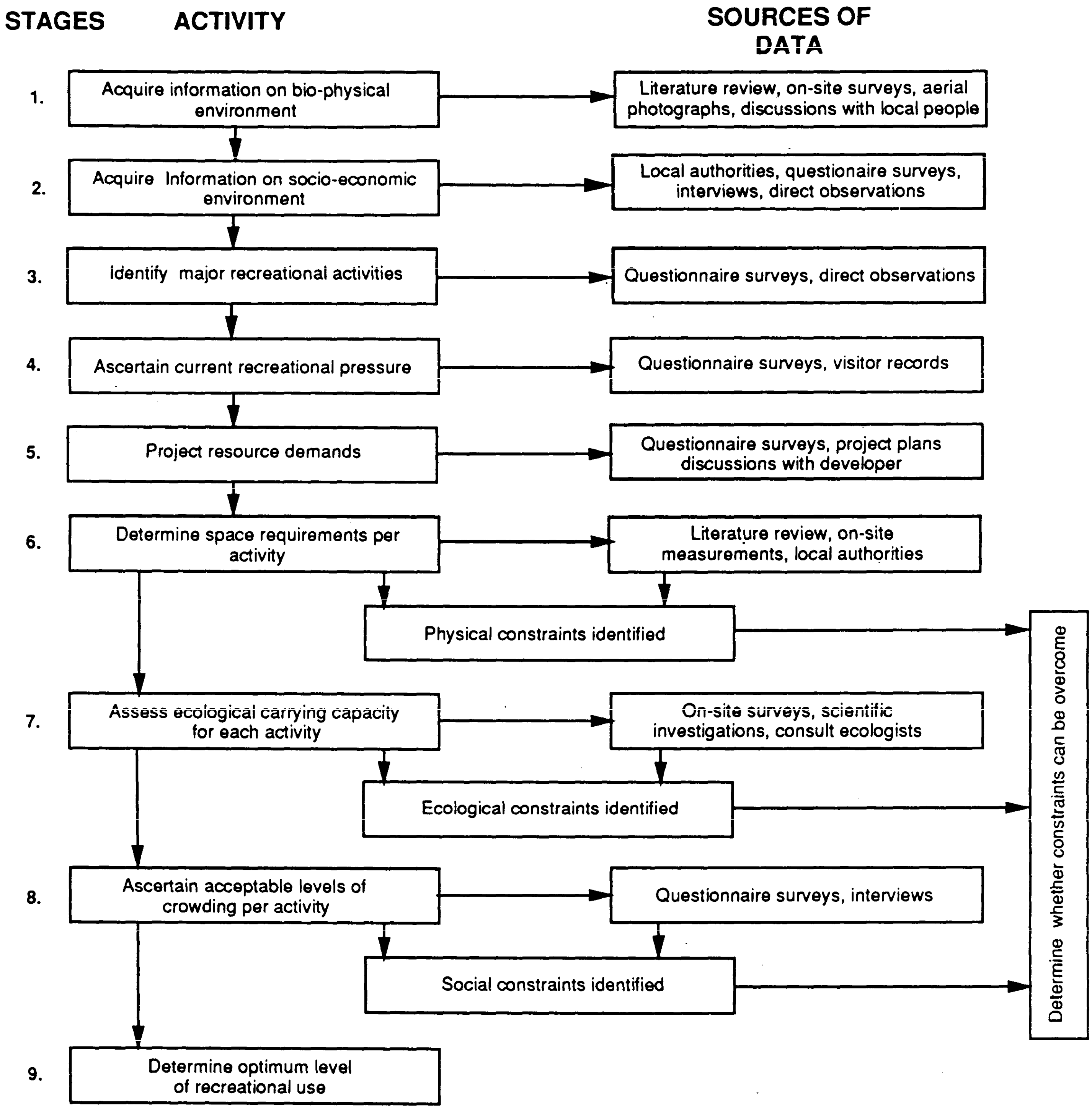


Figure 5: A general procedure for recreational carrying capacity studies (from Sowman, 1987)

from direct observations, questionnaires, interviews, ecological consultants, and the technical literature (boating space standards). Recommendations for regulating current and projected recreational activities to prevent overcrowding were suggested.

Barstad and Karasov (1987) summarized studies of boat use intensity and boater safety related concerns in Minnesota lakes. The study found that perceptions of boating safety varied regionally and temporally. Conditions were perceived to be most crowded (least safe) during weekends and holidays, and in relatively heavily used Minneapolis-St.Paul metro area lakes.

A GENERAL APPROACH

Shelby and Heberlein (1986) provide a general conceptual framework and guidelines for conducting carrying capacity studies. This approach involves both a "descriptive" and an "evaluative" component (Figure 6). The descriptive component details the physical, biological, and social aspects of the recreation system. Information is collected concerning the nature of existing recreational activities, and their social and environmental impacts. The evaluative component defines management objectives and determines the acceptable level of social and environmental impacts.

Preliminary work involves the collection of background information concerning the recreational resource, existing recreational activities, and other pertinent data (Figure 7). Review of this information leads to a decision either to end the study, develop a management plan on the basis of existing information, or conduct a more formal carrying capacity study.

Guidelines for conducting a formal carrying capacity study are discussed in detail by Shelby and Heberlein (1986). A general outline of the carrying capacity assessment process is provided below:

- Organize and evaluate background information.
- Identify in general terms the study objectives and resolve initial issues related to conflicting use.
- Identify potential important ecological, physical (including facility), and social impacts.
- Collect detailed information necessary to define existing conditions, evaluate impacts, and refine study objectives.
- Develop management alternatives that would limit impacts to acceptable levels.
- Select a management strategy.
- Monitor impacts.

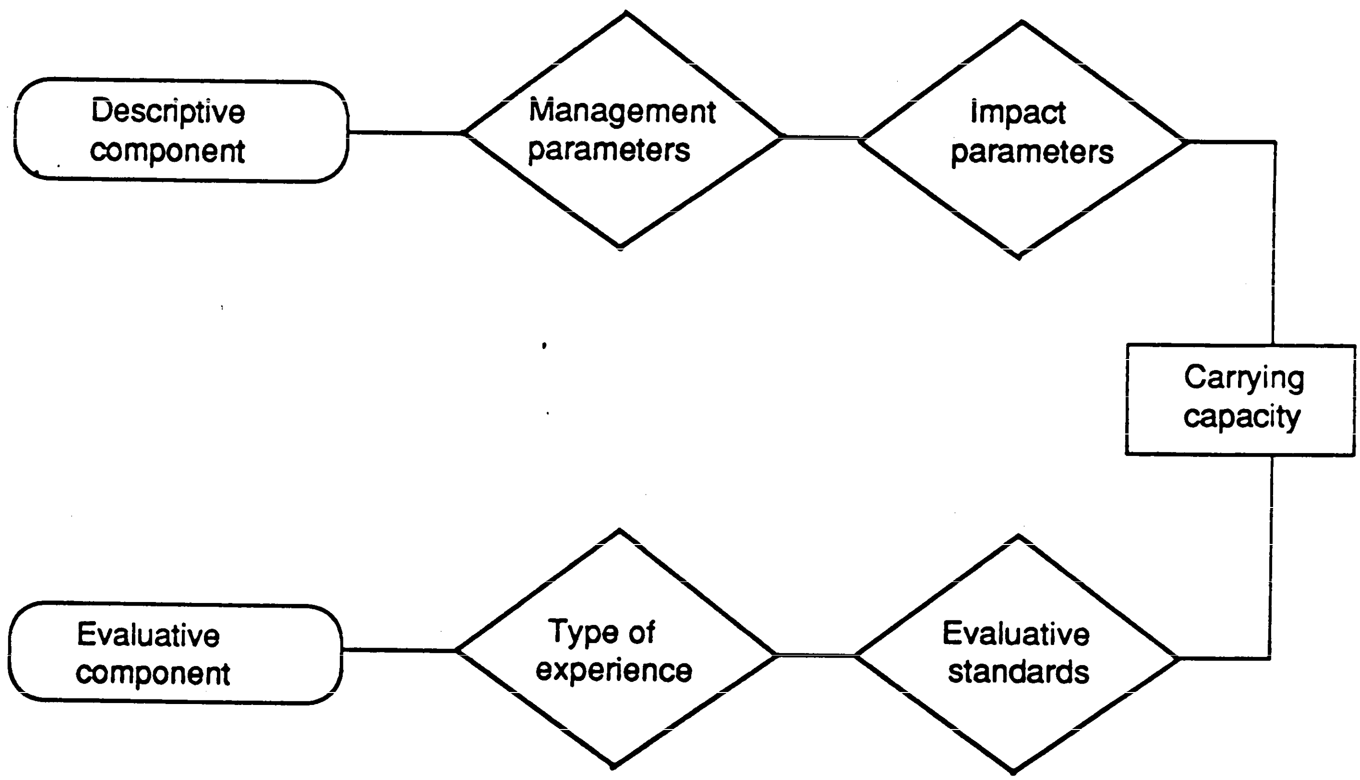


Figure 6: The Shelby and Heberlein (1986) model for carrying capacity studies.

A. General Context in Which Resource Exists

1. Geographical context
   a. Nature of surrounding area
   b. Population centers
   c. Access (roads, air routes, etc.)
2. Political climate
   a. Identify interest groups (activity clubs, conservation organizations, key contacts, landowners, concessions, businesses, influential individuals, interested individuals interested legislators, etc.)
   b. Specify positions of interested groups
   c. What agencies are involved?
      - Jurisdictions of agencies
      - Agency goals and mandates (legal, philosophical)
      - Applicable legislation (federal, state, local)

B. Factors Specific to the Resource

1. Physical description
   a. Terrain
   b. Entry and exit points
   c. Location of focal points, areas of use concentration (camps, attraction sites, put-in and take-out points, parking areas, facilities such as stores)
   d. Land ownership (e.g. public vs. private)
   e. Major factors affecting resource use (e.g. dams, water rights)
   f. Developments and visitor services (e.g. buildings, roads, transportation systems, concessions, outfitters, stores)
2. Management
   a. Who are the managers?
      - Positions, titles
      - Personalities, length of service, flexibility
      - Who makes what decisions ?
      - Formal chain of command
      - Informal chain of command
   b. Management objectives for the resource
      - General
      - Restate in specific operational terms-what do you want to provide? Are objectives flexible?
3. User description
   a. Where do visitors come from and how do they arrive?
   b. Demographic characteristics (age, income, group composition)
   c. Organizational aspects (clubs, etc.)
4. Past and present use levels
   a. People per year and changes and trends over past few years.
   b. Identify problems in general and by area, group, type of use.

C. Recreational Activities

1. What do people do?
   a. Name and describe activities
   b. Travel modes
   c. Travel patterns
      - Time (Day use?, overnight use?)
      - Space (Where do people go?)
2. Detailed description of activity
   a. Ideal
   b. As currently available
   c. Minimal requirements.
   d. Differences between groups (ie. beginners vs advanced
   e. At a minimum, descriptions need to include space necessary, desirable ecological characteristics, and recreational "quality" in relation to number of people.
3. Which activities are (or are not) considered "legitimate
4. Which activities conflict with one another?
5. Are there differences of opinion about whether things are O.K.? For which activities?

D. Substitute Activities

1. Nature of substitutes
2. Specific activities
3. Availability of substitutes
4. Differences in substitutability by activity type and user group.

E. Rough Estimates of Capabilities (specify assumptions regarding technology and norms under each category)

1. Types
   a. Ecological
   b. Physical
   c. Facilities
   d. Social
2. Decide which type of capacity is most likely to:
   a. Be the limiting factor
   b. Require the most information and work

F. Anticipate Implementation Procedure and Possible Impacts

1. Implementation
   a. What will limits be?
   b. Where will they be applied?
   c. How will they be enforced, complied with, etc.?
2. Kinds of impacts
   a. Economic - how will resources be distributed?
   b. Social - how will experience change?
   c. Resource - how will area change physically?
3. Who will be impacted?
   a. All interest groups
   b. "Silent" folks
   c. Users (different impacts for different groups?)

Figure 7: Guidelines for conducting a preliminary carrying capacity study (from Shelby and Heberlein, 1986).

Although this approach has not been applied in detailed studies of small freshwater lakes, it has proved useful for activities as diverse as deer hunting and wilderness river running. The approach has been used to provide boating carrying capacity estimates for Lake Superior's Apostle Island National Lakeshore (Heberlein _et al_., 1986).

The methodology employed by Shelby and Heberlein (1986) appears to work well in a variety of recreational settings. A key constraint in lakes however, may be the frequent occurrence of conflicts between various recreational activities. Unless management techniques such as zoning can resolve user conflicts, this model may be of limited utility in many heavily used recreational lakes. Similarly, the Corps (1980) model appears poorly suited to address multiple use problems. The concept of user preference distances however, appears to be a very useful one which could be incorporated into the Shelby and Heberlein (1986) approach.

OTHER ISSUES INVOLVING LAKE CARRYING CAPACITY

LAKE CHARACTERISTICS

Aside from the relationship between lake size and carrying capacity implicit in space standards, little information is available which relates lake morphology to recreational carrying capacity. Intuitively, one would expect that social carrying capacity for boating would generally increase with increased lake shoreline development (a lake with several embayments, for example, would be expected to have a greater social carrying capacity than a circular lake with the same surface area). This relationship is anticipated because relatively complex lake morphology would tend to reduce the frequency of encounters between boaters. An analogous situation exists in wilderness areas where social carrying capacity is enhanced by vegetation or topographic features which act to screen users from one another (Pigram, 1983). Complex lake morphology may also facilitate the implementation of zoning plans which can reduce user conflicts, and thus increase social carrying capacity (Jaakson, 1971).

Lake depth may be related to the susceptibility of lakes to recreational impacts. Turbulence caused by boating would be more likely to have an adverse impact on turbidity in relatively shallow lakes (or shallow embayments) with silty bottom sediments. Potential for dilution of contaminants (nutrients, petrochemicals) would be greater in lakes with relatively greater volume to surface area ratios. Within lakes, poorly flushed embayments would be most susceptible to adverse water quality impacts due to contaminant loading.

Information concerning watershed soil characteristics can be used to help predict the potential impact of shore-based activities on lake water quality. In general areas with relatively thin soils and steep slopes will be most liable to erosion caused by recreational activities. The recreational carrying capacity of watersheds with apatite (phosphorus) rich soils may be particularly limited.

Various models (see Reckhow, 1979; Reckhow and Simpson, 1980; Barstad and Karasov, 1987) can help predict the sensitivity of lakes to eutrophication, and may be of some value in predicting the impacts of recreational nutrient loading. Klar et al. (1983), for example, used simple models developed by Vollenweider (Figure 8) to evaluate the sensitivity of the Quabbin Reservoir in Massachusetts to increased nutrient loading from recreation or other activities. This technique, and algal bioassay studies, suggested that the reservoir may be sensitive to increased nutrient loading.

The use of lake nutrient models for recreational planning is constrained by the lack of information concerning the magnitude of nutrient loading associated with recreational activities. Furthermore, unless nutrient loading due to recreation is high, or precise data for other model parameters (i.e. flushing rates, nutrient input from other point and non-point sources) is available, it is likely that these models

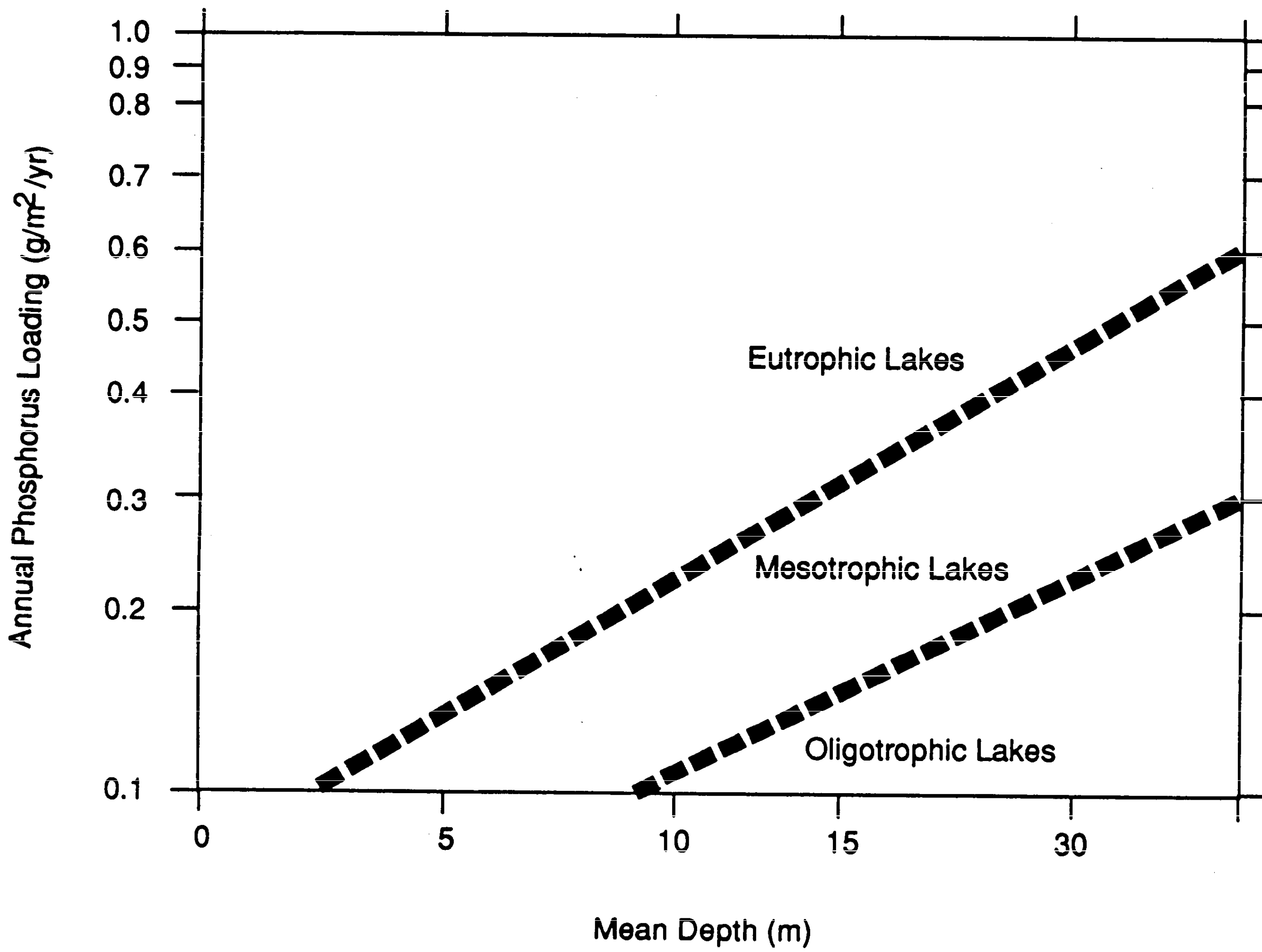


Figure 8: The Vollenweider Model for allowable phosphorus loadings in lakes (from Klar et al., 1983).

will not be sensitive enough to predict the impact of recreational activities on trophic status.

CONFLICTS BETWEEN RECREATIONAL ACTIVITIES

Conflicts frequently occur between individuals or groups pursuing different recreational activities, and can severely complicate carrying capacity studies (Shelby and Heberlein, 1986). Conflicts occur when incompatible activities require the same recreational resource. Examples of activity conflicts likely to occur in freshwater recreational settings are presented in Figure 9. The severity of potential conflicts depends both on the nature of the activities involved, and the attitudes of recreationists (Bury et al., 1983; Pigram, 1983). In some cases, activities are totally incompatible because of safety concerns (e.g. water skiing and swimming). In other cases, the chief concerns are social impacts, and the activities may be able to coexist to some degree.

Conflicts can occur as a result of direct or indirect encounters between users. Individuals hiking along a lakeshore trail, for example, might be impacted by the noise of nearby motorboats and litter left along shore by fishermen. In some cases, conflicts may be difficult to detect because one activity may displace the occurrence of other activities. A lake heavily utilized for power boating, for example, may be largely avoided by canoeists. User surveys would be unlikely to reveal the significance of such a conflict because of the self-selected absence of canoeists. In many lakes conflicts exist between shorefront property owners and users with access to the lake via private or public docks and launching facilities. In these situations, user surveys must be designed so that needs and preferences of various user groups can be ascertained.

RECREATION AND WATER SUPPLY

Historically, recreation on water supply reservoirs in the Northeastern United States was severely restricted or prohibited (C.E.Q., 1975). Recreation was limited largely because of public health concerns related to the potential contamination of water supplies with human wastes. With modern water treatment measures (i.e. filtration and chlorination), however, any wastes discharged by recreationists pose little risk to finished water supply quality (Peavy and Matney, 1977).

Compatibility of Uses on New Hampshire's Great Ponds

KEY:

- . No Conflict
- ○ Minor Conflict
- ◑ Major Conflict
- ● Incompatible Uses

	Swimming	Scuba Diving	Snorkeling	Sailboarding	Boating, Nonpower	Boating, Sailing	Boating, Limited Power	Boating, Electric	Boating, Unlimited Power	Boating, Excursion	Hovercraft	Water Skiing	Jet Boating/Skiing	Fishing, Boat	Fishing, Shoreline	Hunting	Species Protection	Natural Areas	Solitude, Nature	Snowmobiling	Ice Boating	Fishing, Ice
Swimming		•	•	•	•	•	○	○	◑	•	●	○	●	○	○	○	○	○	○	•	•	•
Scuba Diving	•		•	○	•	○	●	○	●	•	●	●	●	○	○	○	•	○	○	•	•	•
Snorkeling	•	•		○	•	○	●	○	●	•	●	●	●	○	○	○	•	○	○	•	•	•
Sailboarding	•	○	○		•	•	○	•	●	•	●	◑	●	○	•	○	○	○	○	•	•	•
Boating, nonpower, canoe	•	•	•	•		•	○	•	◑	•	◑	◑	◑	•	•	•	•	•	•	•	•	•
Boating, sail	•	○	○	•	•		○	•	●	•	◑	◑	◑	○	•	•	•	•	•	•	•	•
Boating, limited power	○	●	●	○	○	○		•	•	•	•	•	•	◑	○	•	○	○	◑	•	•	•
Boating, electric	○	○	○	•	•	•	•		○	•	○	•	○	○	○	•	○	○	○	•	•	•
Boating, unlimited power	◑	●	●	●	◑	●	•	○		•	•	•	•	●	●	●	◑	●	●	•	•	•
Boating, excursion	•	●	●	•	•	•	•	•	•		○	•	○	◑	○	•	○	•	◑	•	•	•
Hovercraft	●	●	●	●	◑	◑	•	○	•	○		◑	○	●	●	●	◑	●	●	○	○	●
Water skiing	○	●	●	●	◑	◑	•	•	•	•	◑		○	●	●	•	◑	●	●	•	•	•
Jet boating/skiing	●	●	●	●	◑	◑	•	○	•	○	○	○		●	●	•	◑	●	●	•	•	•
Fishing, boat	○	○	○	○	•	○	◑	○	●	◑	●	●	●		•	•	•	•	•	•	•	•
Fishing, shoreline	○	○	○	•	•	•	○	○	●	○	●	●	●	•		•	•	•	•	•	○	•
Hunting, waterfowl	○	○	○	○	•	•	•	•	●	•	●	•	•	•	•		•	○	○	•	•	•
Species protection	○	•	•	○	•	•	○	○	◑	○	◑	◑	◑	•	•	•		•	•	◑	•	•
Natural areas	○	○	○	○	•	•	○	○	●	•	●	●	●	•	•	○	•		•	◑	•	•
Solitude, nature enjoyment	○	○	○	○	•	•	◑	○	●	◑	●	●	●	•	•	○	•	•		●	•	•
Snowmobiling	•	•	•	•	•	•	•	•	•	•	○	•	•	•	•	•	◑	◑	●		○	◑
Ice boating	•	•	•	•	•	•	•	•	•	•	○	•	•	•	○	•	•	•	•	○		○
Fishing, ice	•	•	•	•	•	•	•	•	•	•	●	•	•	•	•	•	•	•	•	◑	○	

Figure 9: Conflicts between lake-based recreational activities (from New Hampshire State Planning Office, 1985).

MANAGEMENT PRACTICES

The following sections discuss management practices which can enhance or preserve the recreational carrying capacity of lakes.

PROVISION AND MAINTENANCE OF SUPPORT FACILITIES

The provision and maintenance of support facilities can enhance recreational carrying capacity, while preserving the environmental quality of a recreational resource. Facilities which may need to be provided include toilets, parking lots, boat docks, boat ramps, moorings, campsites, picnic areas, and hiking trails. Information concerning the design and maintenance of these facilities is provided by Fogg (1981), Douglas (1982), and Hendee et al. (1978). Placing limits on the availability of facilities such as parking lot spaces and boat moorings is a useful management technique for meeting lake carrying capacity guidelines.

To preserve lake water quality, sanitation facilities must be provided to collect and dispose of human wastes. Provision of toilets is critical to reducing improper discharges along lakeshores by swimmers, campers, fisherman, and other recreationists. Facilities should be properly designed, situated, and maintained to encourage use, and minimize the drainage of effluent into lakes. Depending on level of use, the sensitivity of a lake to nutrient loading, and economic considerations, facilities can range from simple pit privies to elaborate septic systems. In instances where lakes are sensitive to nutrient loading, the use of pump-out vault toilets should be considered in recreation areas.

The control of waste discharge from leisure craft is a more complicated problem. Facilities for offloading wastes from on-board holding tanks should be provided if larger craft are permitted on a lake. In some instances, holding tanks may be sealed to insure against illegal discharges. In some lakes no offloading facilities are provided in order to discourage lake use by larger boats (Courtland Cross, pers. commun.). It is possible, however, that this policy could lead to increased illegal discharges from portable commodes.

SITE SELECTION

The selection of the optimal location for facilities is a key facet of recreational planning. Careful site selection can minimize safety hazards, conflicts between various recreational activities, and environmental impacts. General guidelines concerning the proper placement of campsites, swimming beaches, boat ramps, and other support facilities are provided by Hendee et al., (1978), Fogg (1981), Douglas (1982), the U.S. Dept. of Interior (1980), and Marion and Merriam (1985).

Swimming areas should be located at sites with a gently sloped, sandy or gravelly substrate. Because of safety concerns, obstacles such as large rocks and logs should be absent from the area or removed. Areas with submerged weed beds should be avoided. Where possible, swimming areas should be situated in well flushed location to minimize the potential buildup of high bacterial counts. In lakes or reservoirs used for water supply, beaches should be well isolated from water intakes.

Marinas and boat ramps should be placed in areas where flushing will minimize the potential buildup of contaminants. Where possible, sites with submerged weed beds, soft bottoms, or sensitive shorelines should be avoided to minimize environmental impacts.

Soil characteristics and topography are key to the selection of suitable locations for campsites, picnic areas, hiking trails and other shore-based facilities. Kuss and Morgan (1986) provide guidelines for using the Universal Soil Loss Equation to estimate the carrying capacity of sites for recreational activities. This technique predicts the susceptibility of a site to disturbance by integrating information concerning soil characteristics, tree canopy types, canopy densities, ground cover types, topographical factors (i.e. slope and aspect), and rainfall. In general, sites with steep slopes and shallow soils with low organic content should be avoided. Potential for shoreline erosion can be minimized by selecting sites with bedrock outcrops or cobble at the shoreline, and by avoiding steeply sloped banks (Marion and Merriam, 1985). Selection of lakeshore sites is also dependent on the availability of suitable sites for sanitary facilities.

BEHAVIOR MODIFICATION

The behavior of recreationists can be altered to optimize carrying capacity by zoning and other sorts of management techniques. Zoning is widely used to regulate recreation in lakes. It is useful in reducing conflicts between various activities, improving public safety, and protecting environmental resources. Jaakson (1971) provided a thorough discussion of the concept and defined three primary types of zones in lakes: shoreline, open water, and wildlife "activity zones".

The shoreline activity zone was defined to extend about 200-300 feet from shore, or to the five foot depth contour. Jaakson suggested limiting boating in the shoreline zone to avoid conflicts with activities such as swimming, and to minimize adverse environmental impacts. A speed limit of 5 miles per hour for boating traffic and the prohibition of power boat movement parallel to shore was proposed.

The open water activity zone consists of the remainder of a lake beyond the shoreline zone (in small shallow lakes or embayments this zone would be absent). In large lakes with complex morphology, this zone could be further subdivided to reduce conflicts between various sorts of open water activities (i.e. water skiing; power boating, sail boating).

The wildlife activity zone was proposed to protect a portion of the lake ecosystem from adverse recreational impacts. This zone would include a portion of the littoral zone and adjacent shoreline habitat. Jaakson proposed limiting recreational activities in this zone to sedentary or slow moving pursuits such as canoeing, fishing, and nature observation.

Brown et al. (1979) summarized the types of water surface zoning techniques employed in the United States in the late 1970's. Regulations were classed into five broad categories:

- Restrictions on boat speed and horsepower
- Special Use Zones (e.g. no motor zones, no boat zones, slow/no wake zones).
- Time Zoning (e.g. limiting water skiing or power boating to only certain times during the day, seasonal use restrictions).
- Protective Space Zoning (e.g. a protective zone around slow moving boats).
- Limited Density Zones (e.g. restricting the number of water skiers using a lake at any one time).

Regulations were typically tailored for individual lakes on a case by case basis, within the framework of state boating regulations.

For this study several states were contacted to survey current water zoning policies. Wisconsin has restricted power boats to slow-no wake speeds on lakes smaller than 50 acres since 1983. No regulations limiting the size (horsepower) of motors are in place because of a recent court case which found such restrictions to be unconstitutional (Dale Morrey, pers. commun.).

Regulations in Minnesota lakes frequently involve the establishment of speed limits and slow-minimum wake zones (Minnesota Dept. Nat. Res., n.d.). Shore protection zones range in width from 100 to 300 feet. Motorboats are banned in some lakes, and in others only those powered by electric motors are allowed. A survey of Minnesota boaters indicated that those who perceive conditions to be crowded are strongly in favor of zoning restrictions (Barstad and Karasov, 1987). Speed-no wake zoning and, to a lesser extent, limitations on horsepower and boat type/size were the most frequently requested restrictions.

Regulations established by the Vermont State Water Resources Board frequently prohibit the use of motorboats with internal combustion engines or place strict (5 mile per hour) speed limits (Vermont Dept. Motor Vehicles, 1987). Shore protection zones are established for several lakes. Houseboats and water skiing are also frequently prohibited. Surveys of Vermont recreationists indicate that a majority support various zoning restrictions (Lindsay and Rupe, 1979). Among user groups, fishermen were most supportive of regulations while water skiers were the least supportive group.

In New Hampshire lakes, regulations in place most frequently limit boat speeds to less than 10 miles per hour or prohibit motorboat (or outboard motor) use entirely (New Hampshire Dept. of Safety, 1987). In some restricted use lakes only those boats powered by internal combustion engines are prohibited. Shore protection zones are established for only a few lakes.

In order to be effective, zoning regulations should be well publicized and enforceable. Adequate resources must be allocated for public education (signs, leaflets, buoys, etc.) and enforcement. Efforts to explain the rationale and benefits associated with use restrictions are likely to increase public acceptance and compliance (Frost and McCool, 1988).

User numbers in recreational settings can be controlled by various sorts of rationing techniques. These include systems which limit entry based on reservations, lotteries (chance), queuing (first-come, first-serve), and user fees. Rationing can be employed to limit lake use on both a daily and seasonal basis. Queuing is used, for example, on Walden Pond (Massachusetts) where parking lot gates are closed once carrying capacity is exceeded. In some lakes rationing might be useful in allocating, on a seasonal basis, a limited number of boat moorings. Hendee et al. (1978) provide discussions of the relative merit, and problems associated with various rationing techniques in wilderness situations. Much of their discussion, however, is applicable to other recreational settings.

MITIGATION METHODS

Although management efforts should focus on minimizing the environmental affects of recreational activities, it is also possible to mitigate for some unacceptable adverse impacts. Embankments denuded of vegetation and prone to erosion can be stabilized and revegetated. Technical information concerning the use of innovative bioengineering techniques to stabilize slopes is presented by Allen (1978), Edminster et al. (1949), Gray and Leiser (1982), and Schiechtl (1980). Information concerning the selection of plant material for use in riparian habitats is provided by Hightshoe (1978), E.P.A. (1976), and Whitlow et al. (1979). Useful guidelines on the wildlife value of various plants are provided by Martin et al. (1951) and Degraaf and Witman (1979).

Many recreation areas with erosion problems may be located on poorly suited sites. In some instances it may be desirable and cost effective to to abandon these areas in favor of more suitable locations.

Over fishing of game fish has long been mitigated by stocking programs. Disruption of water fowl breeding habitat can be mitigated for by provision of artificial nesting sites (e.g. wood duck boxes, and artificial floating islands for loons).

Recreational carrying capacity can be enhanced by the control of infestations of aquatic weeds such as the eurasian water millfoil. Although control strategies may be costly, and entail some environmental costs, adverse impacts may be outweighed by the benefits both to recreationists and aquatic resources.

THE ENVIRONMENTAL IMPACTS OF RECREATION ON LAKES

This section provides a brief literature review concerning the environmental impacts of recreational activities on temperate lakes. Earlier reviews concerning the environmental effects of recreation on aquatic and/or terrestrial resources include those of Goldsmith (1974), Speight (1973), Wall and Wright (1977), Liddle and Scorgie (1980), Peavy and Matney (1977), Boyle and Samson (1985), Kuss and Graefe (1985), Kuss (1986), Edington and Edington (1986), and Hammitt and Cole (1987). Bibliographies of the relevant literature are provided by Stankey and Lime (1973), Pearce and Eaton (1983), and Boyle and Samson (1983).

WATER QUALITY

Microbial Contamination

Numerous studies have investigated the impact of recreational activities on the coliform concentrations in lakes and reservoirs. Most have failed to establish a clear link between bacterial counts and recreation activities (see Rhode Island State Planning Program, 1974; Peavy and Matney, 1977).

A few studies indicate that shore-based activities such as bank fishing and camping may result in elevated coliform counts in lake waters. King and Mace (1974) found that coliform bacteria levels in remote Minnesota lakes were higher near campsites than at adjacent control sites. Soils were shallow, and effluent from pit toilets was considered the most probable source of contamination. Barbaro *et al*. (1969) provide circumstantial evidence that improper discharges by bank fisherman contributed to elevated coliform counts in a Massachusetts reservoir.

A major potential source of bacterial contamination is the improper discharge of wastes from leisure craft (Peavy and Matney, 1977). Several studies have noted increased concentrations of bacteria in the vicinity of marinas in freshwater lakes or reservoirs. Elevated concentrations probably result from the improper handling of wastes at offloading and treatment facilities, or from the illegal discharges of wastes from holding tanks.

Individuals shed a considerable number of bacteria into recreational waters while swimming (Hanes *et al*., 1982). Although several studies indicate that swimming may cause localized increases in bacterial density (see Peavy and Matney, 1977; Sherry, 1986), others have found no correlation between bacterial counts in recreational waters and the number of swimmers (Sekla *et al*., 1982). The potential for increased concentrations of pathogens is likely to be greatest in situations where swimming beaches are located in poorly flushed embayments (Burton, 1982; Johnstone and Babb, 1986).

One measure of carrying capacity with respect to microbial contamination would be the level of use at which recreational activities increase concentrations of pathogens to the point where bathers are at a significant risk of infection (see Sekla et al., 1987). Several recent epidemiological studies have related increased risk of gastrointestinal illness to enterococci concentrations in fresh and marine waters . The United States Environmental Protection Agency has recommended a 30 day mean criteria of 33 enterococci per 100 ml in fresh waters (U.S. E.P.A., 1986). At present, few studies have related enterococcal inputs from recreational activities to this standard. Selka (et al. 1987), however, found that enterococcal concentrations in a very heavily used swimming beach in Manitoba were 25/100 ml.

In summary, most previous studies suggest that recreational activities have a minimal impact on the microbial flora of lakes. Significant increases in bacterial counts are likely to occur only in localized areas (i.e. campsites, beaches, and marinas).

Nutrients

Recreational activities can add nutrients to lake ecosystems via the direct discharge of wastes (i.e. human excrement and urine, soaps, phosphorous rich oils, garbage) or via the runoff of nutrient rich sediments from sites disturbed by human activities.

No field studies reviewed measured nutrient loading resulting from indirect or direct human wastes discharged by recreationists. Potential loading rates which assume that all wastes produced by individuals eventually enter the lake ecosystem are on the order of 2-3 grams total phosphorus and 8-9 grams total nitrogen per user per day (Bniska, 1985; see Klar et al., 1983). Actual loading rates may be somewhat less, and would depend on the utilization and efficiency of waste collection systems.

A few studies have demonstrated increases in lake nutrient concentrations as a result of recreational activities. Total phosphorus levels in remote Minnesota lakes were significantly higher near primitive campsites than at adjacent control locations (King and Mace, 1974). Effluent from shallow pit toilets, detergents, and outboard motor fuel were likely sources of phosphorus. Dickman and Dorais (1977) found strong evidence that erosion of phosphorus (apatite) rich soils caused by human trampling resulted in the eutrophication of a small (11.6 ha) Canadian lake.

There is evidence that mixing by outboard motors can increase nutrient exchange between bottom sediments and lake waters. Field studies by Yousef et al. (1980) found that mixing by motorboats in two shallow, muddy bottomed, Florida lakes significantly increased turbidity and phosphorus levels in lake waters. Increases in chlorophyll a concentration (a measure of algal productivity) were also noted a short time after mixing, but could be attributable to suspended benthic algae. Phosphorus released from suspended sediments would either be rapidly taken up by algae or bacteria or (under aerobic conditions) form an insoluble precipitate with ferric hydroxide.

Suspended Sediments

Various recreational activities have the potential to elevate suspended solids concentrations in lake waters. Bottom sediments can be resuspended by motorboats (e.g. Wright, 1982; Gucinski, 1982) and presumably to some extent even by less intense activities such as swimming. The amount of sediments resuspended by boating will depend primarily on the type of boat and boat velocity, grain size of bottom sediments, and water depth (Garrad and Hey, 1987). The amount of material suspended is likely to be greatest in shallow waters with muddy, unvegetated bottoms. The occurence of prolonged water quality impacts would depend on the frequency and intensity of boating, and the settling rate of suspended material.

Boat wakes can cause shore erosion (Liddle and Scorgie, 1980), and could conceivably increase the ambient suspended solid concentration in nearshore waters. Shore erosion resulting from boat traffic is most likely to be a problem in waterways with narrow channels, sharp bends, or areas with steep, poorly vegetated banks (Miller et al., 1987).

On-shore activities such as bank fishing, boat launching, hiking, and camping can disturb soils and vegetation, and are likely to result in increased transport of sediments into lakes, stream and reservoirs. Although there is considerable anecdotal evidence that recreation can lead to increased erosion (e.g. Dickman and Dorais, 1977), few studies have examined impacts to water quality.

Various actions can help minimize the impact of recreation on suspended sediment loading in lake and reservoirs. Resuspension of bottom sediments can be minimized by zoning ordinances which limit boat velocities and/or boat access to sensitive areas (i.e. shallow, sheltered embayments with soft bottoms). Experimental studies can be used to establish threshold velocities at which which very little resuspension of bottom sediment occurs (Garrad and Hey, 1987).

Contaminants

Two-stroke outboard motors release a variety of contaminants into lake waters through engine exhausts and, in older (pre 1972) models, through crankcase drainage (see Jackivicz and Kuzminski, 1973 a). Principle contaminants released into waters by exhausts are nonvolatile oils (lubricating oils), volatile oils (gasoline), phenols, and lead (English et al., 1963). Montz et al. (1982) found that the major water soluble hydrocarbons found in exhausts are monocyclic benzene derivatives.

Older motors without crankcase recycling discharged on average, 10 - 20 % of fuel into lake waters. Typical inputs of gasoline, lubricating oil, and other petrochemicals via spillage by boaters have not been quantified.

Few studies have investigated the effects of contaminants released by boating on lake water quality. English et al. (1963) conducted experimental field studies and noted that levels of hydrocarbons in water increased in a small pond and lake over a summer with increased cumulative fuel consumption. Byrd and Perona (1980) noted a correlation between the number of boats launched and lead concentrations in water from the boat dock area of a large (1420 ha) California lake. Lead concentrations in the main body of the lake, however, was not significantly affected by boating. Several studies have noted that contaminates discharged from outboard motors can form visible surface slicks (Jackivicz and Kuzminski, 1973 b). Hallock and Falter (1987) concluded that nitrogen and phospshorus released from boat engines was an insignificant source of nutrient enrichment in an Idaho lake.

In marine waters, Gschwend (see Montz et al., 1982) noted higher concentrations of volatile organic compounds (benzenes) from Vineyard Sound (Massachusetts) immediately after summer weekends in which recreational activity were greatest. Voudrais and Smith (1986) noted elevated concentrations of petrochemically derived hydrocarbons in bottom sediments from estuarine marinas. Boat ramps should be placed in well flushed areas to avoid potential buildup of hydrocarbons and other pollutants.

Angling Litter

Several recent studies in Great Britain have quantified the amount of angling litter (fishing line, lead sinkers, and hooks) deposited by fisherman (Bell, et al. 1985; Forbes 1986; Edwards and Cryer 1987). Estimates of the amount of fishing line lost by anglers are on the order of 2.5 to 5 meters per visit. Estimated loss rates for sinkers range from 2-3 to 4-7 per visit. As might be expected, the highest densities of sinkers are found near shore, and near favored fishing sites. In one study, 95 % of all sinkers recovered were within 2.5 meters of localized fishing sites. Cryer et al. (1987) suggest that dissolution of lead shot probably takes at least several decades, so high densities of sinkers are likely to accumulate at heavily used sites. Although lead sinkers are very unlikely to adversely impact lake water quality, their potential impact on water fowl can be of great concern.

FISH

Although there is an enormous amount of literature available concerning the management of sport fisheries in inland lakes, little is known concerning the affects of recreational activities (other than fishing) on fish. Several studies have determined that high concentrations of outboard motor exhausts can be toxic to various fish species (see Jackivicz and Kuzminski, 1973 b; Brenniman et al., 1979). Acute toxicity studies indicate that motor boat exhausts are lethal to 50 % of test fish at concentrations corresponding to fuel use levels of 1 gallon of fuel per 1,000 - 3000 gallons of receiving water. The affects of chronic, long-term exposure to low concentrations of exhausts was not determined in these studies.

The flesh of fish exposed to outboard motor exhausts and other petrochemicals can acquire an unpleasant taste. Although difficult to extrapolate to field situations, experimental studies suggest that outboard motor exhausts (including crankcase drainage) are unlikely to taint fish flesh, except perhaps in heavily used lakes or poorly flushed embayments. The fuel use threshold at which tainted fish flesh can be detected is about one gallon of fuel per 300,000 gallons of lake water (Jackivicz and Kuzminski, 1973 b). Stewart and Howard (1968) indicated a use level threshold of about 8 gallons of fuel per season per million gallons of lake water. Using this value, the fuel utilization threshold for a 10 acre lake with a mean depth of 10 feet would be about 260 gallons per season. Presumably, reduced exhaust emissions due to crankcase recycling in newer motors would substantially increase this threshold.

Oates (1976) found that lead concentration in fish from Kansas lakes heavily used for boating did not differ significantly from that of fish from lakes on which boating was prohibited.

There are apparently no reports in the literature which evaluate the significance of suspended sediments derived from recreation to fish and other aquatic biota. The general impacts of suspended sediments on aquatic biota have been reviewed in detail by Gammon (1970), Stern and Stickle (1978), and Wilber (1983). Fish are generally tolerant of high concentrations of suspended sediments, and are unlikely to be significantly affected by short term periodic exposure to boat generated turbidity.

Early studies by Lagler et al. (1950) found that motor boats could disturb nesting male bluegill, pumpkinseed, and largemouth bass. Mueller (1980) also found that boating disturbed the nest guarding behavior of male sunfish, and resulted in increased egg loss due to predation. Fish were disturbed more readily by relatively slow moving boats. Paddle boats passing close to the nest were more disruptive than motor boats passing at a similar distance and velocity.

AQUATIC INVERTEBRATES

Boating has the potential to adversely impact aquatic invertebrates by disturbing benthic habitats and via the release of contaminants into the water. Lagler et al. (1950) found that repeated use of small outboard motors (194 total hours over a 2.5 month period) along a set course within a small pond substantially reduced invertebrates abundance in the affected area. Marnell et al. (see Liddle and Scorgie, 1980) reported that benthic invertebrates in shallow zones of rivers may be disrupted or eliminated by canoeing.

Kuzminski et al. (1974) conducted static bioassays on the effect of outboard motor exhausts (including crankcase drainage) on several aquatic invertebrates. Results suggest that even the most sensitive invertebrate species is unlikely to suffer lethal affects unless dilution of exhausts by lake water is severely limited.

Laboratory studies suggest that periodic exposure to elevated turbulence and suspended solid concentrations can have an adverse physiological impact on several species of freshwater mussels (Aldridge et al., 1987). Reduced filtering rates (feeding) were noted in clams exposed to elevated suspended solid levels for only several minutes every three hours. It is possible that periodic disturbances by motor boats could have similar impacts.

Placement of groundbaites to attract fish is widely practiced by anglers in the United Kingdom, and can significantly alter benthic invertebrate communities in localized areas (Cryer and Edwards, 1987).

WATER FOWL

A large number of studies suggest that recreational activities can have a deleterious impact on water fowl (e.g. Tuite et al. 1984; Cooke 1987; see Little and Scorgie, 1980). Water fowl can be adversely impacted both by direct disturbances, and by habitat degradation resulting from recreation, or recreational facilities. Recreational impacts on water fowl and other wildlife range from low level stress to direct mortality (Figure 10).

Disturbances by bank fisherman, boaters, and others can reduce the abundance and/or alter the distribution of water fowl on lakes and reservoirs. Human disturbances can be especially detrimental during nesting and brood-rearing periods. Disturbances during this time can lead to increased egg or chick mortality due to nest abandonment or predation.

Category of Impact	Description of Impact
Direct Mortality	Immediate, on-site death of an animal.
Indirect Mortality	Eventual, premature death of an animal caused by an event or agent that predisposed the animal to death.
Lowered Productivity	Reduced fecundity rate, nesting succes, or reduced survival rate of young before dispersal from nest or birth site.
Reduced Use of Refuge	Wildlife not using the refuge as frequently or in the manner they normally would in the absence of visitor activity.
Reduced Use of Preferred Habitat	Wildlife use is relegated to less suitable habitat due to visitor activity.
Aberrant Behavior/Stress	Wildlife demonstrating unusual behavior or signs of stress that are likely to result in reduced reproductive or survival rates.

Figure 10: Potential visitor impacts on wildlife (from Purdy et al., 1986).

Water fowl on relatively remote lakes with little previous use may be more sensitive to disturbance by human activities than those adapted to more heavily used areas. Overall, the continued utilization of lakes and reservoirs by some water fowl species may depend on the existence of areas not easily assessable to boaters or other individuals (Batten, 1977; Cooke, 1987).

Breeding areas for colonial water fowl such as great blue herons can be protected by zoning (Vos et al., 1985). Buffer zones should be established before birds arrive at breeding sites in the spring and be maintained until sites are deserted for the year after fledging. Buffer zones should encompass the greatest distances at which recreational activities cause birds to flush at any time throughout the breeding season plus an additional buffer distance because birds may be stressed by humans prior to when they take flight. Because responses are likely to vary between sites, recommended distances should be based on observations and experimental studies for each individual colony. Guidelines for creating buffer zones on land are provided by Buckley and Buckley (1978). Buoys can be used to demarcate boundaries in water.

Various studies suggest that recreational activities can have an adverse impact on loons. Human disturbances can reduce the number of breeding loons on lakes (Vermeer, 1983), and reduce the number of young produced per nest (Titus and VanDruff, 1981). Disturbances may result in abandonment of nests or loss of eggs or chicks can occur due to predation. Because chicks occur predominately close to shore, near-shore recreation may be more detrimental than activities in deeper waters (Strong and Bissonette, 1989). Recreational impacts may be tempered somewhat because some loons can become habituated to human activities (Heimberger et al., 1983).

Because loons reuse nesting sites from year to year (Strong et al., 1987), it is important to protect known nesting and nursery areas. Artificial islands can provide high quality nesting sites for loons in developed lakes lacking suitable sites. Monitoring and educational programs may reduce impacts from human disturbance (Sutcliffe, 1979).

The bottom sediments of lakes and wetlands utilized by hunters may contain high concentrations of spent shot (e.g. Spray and Milne, 1988). The ability of diving ducks and other water fowl to pick up this shot while foraging for benthic invertebrates and plants is well established, as is the subsequent poisoning of water fowl by ingested lead shot (Bellrose, 1976). Roscoe et al. (1979) estimates that up to two million ducks and geese die of lead poisoning in the United States each year. Although lead shot is still in use in the United States, measures have been taken to protect water fowl by establishing non-toxic (steel) shot zones in some states.

The potential threat of lead sinkers discarded by fisherman has also been recognized in recent years. In particular, sinkers have been implicated in the deaths of mute swans in England, Scotland and Ireland (see Thomas et al., 1987). There are no significant problems involved in producing sinkers from non toxic materials, and there use has recently become mandatory in the British Isles.

Water fowl mortality resulting from entanglement in discarded fishing line has also been frequently reported (e.g. Edwards and Cryer, 1987).

OTHER WILDLIFE

Little is known concerning the impacts of lake based recreation on other wildlife. In Florida, collisions with boats account for a substantial proportion of deaths of the federally endangered West Indian Manatee (O'Shea et al., 1985). Interactions between anglers and the otter in great Britain were discussed by Jefferies (1987).

AQUATIC VEGETATION

Emergent macrophytes growing along lakes and rivers are susceptible to trampling by fishermen, boaters, swimmers, and others utilizing the shore zone (Murphy and Pearce, 1987; Liddle and Scorgie, 1980). In some instances impacts may be largely limited to narrow access trails. In others, heavy recreational pressures may severely degraded emergent plant communities. Experimental studies indicate that tall emergent macrophytes growing near shore are generally more susceptible to trampling than relatively short species found at higher elevations (Rees and Tivy, 1978).

Boating has the potential to impact submerged aquatic plants in several ways (Figure 11). Plants can be damaged as a result of direct contact (i.e. cutting by propellers or uprooting by paddles), or indirectly as a result of the erosive action of boat wash. Turbidity generated by boating can reduce light availability, and may reduce macrophyte productivity. Although no studies have quantified the affects of boating on submerged macrophytes in lakes, Murphy and Eaton (1983) found that the macrophyte standing crop in small English canals was reduced when boat traffic exceeded about 2000-4000 passages per hectare /meter depth/year. Taylor and Erman (1979) attributed changes in submerged macrophyte communities of alpine lakes to increased nutrient loading caused by shore-based activities.

Recreational boat traffic has been implicated in the dispersal of aquatic weeds between lakes (e.g. Johnstone et al., 1985), and thus can potentially have a major indirect impact on submerged aquatic plant communities. Stringent measures should be employed to prevent the introduction of aquatic weeds into uninfested lakes and reservoirs. Boater education campaigns, inspections, and weed control in the vicinity of boat ramps in infested lakes can help reduce the threat of interlake dispersal.

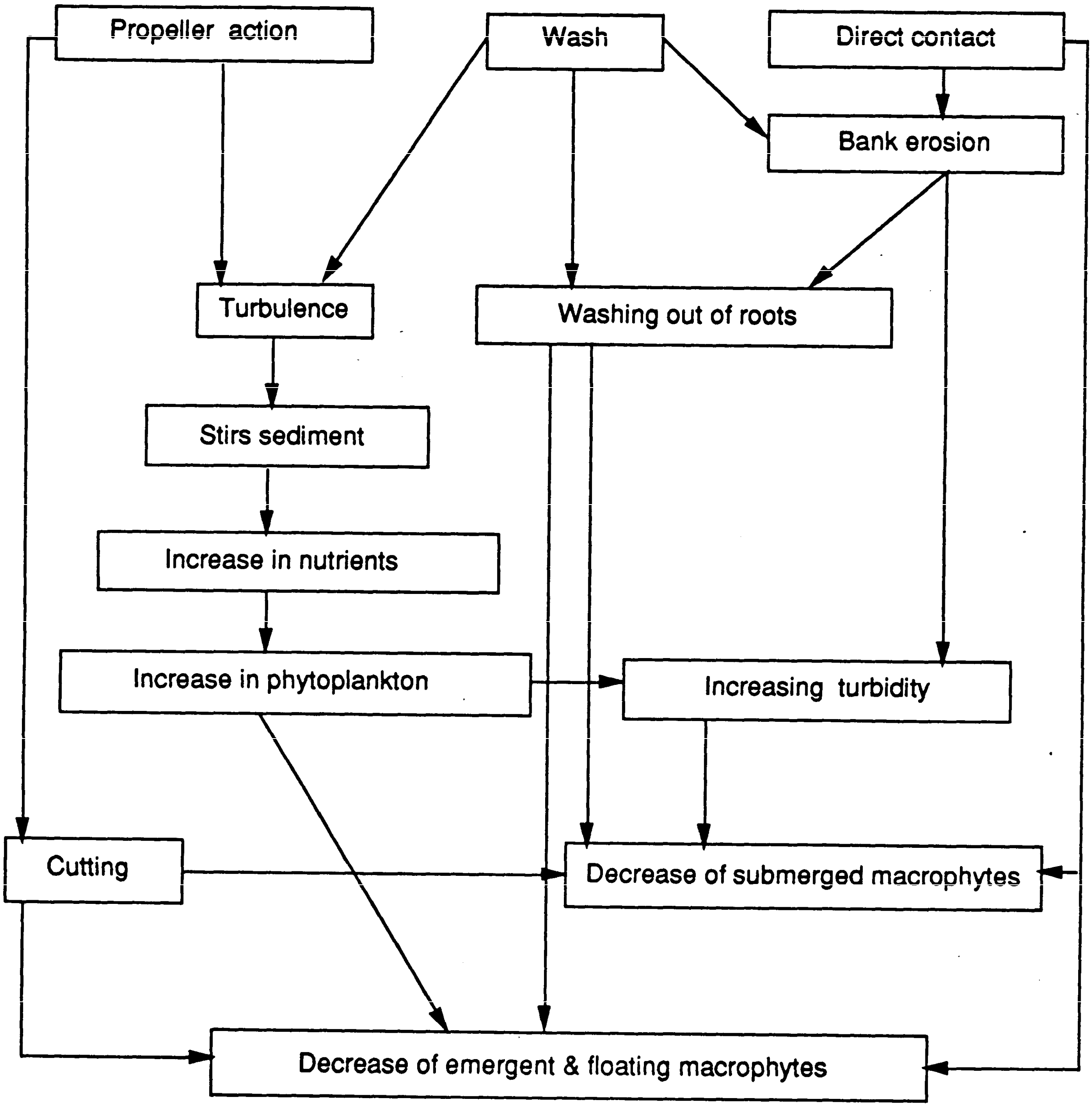


Figure 11: Potential impacts of boating on aquatic vegetation (from Liddle and Scorgie, 1980).

CONCLUSIONS

This report is intended to provide New Hampshire water resource planners with a general understanding of the recreational carrying capacity concept and related issues involving the management of lake resources for recreation. Principal conclusions of this study are as follows:

1. Although recreational carrying capacity is a highly subjective concept, it has proven to be a useful framework for developing management policies in a variety of recreational settings.

2. There is no standard approach for determining recreational carrying capacity. Guidelines for conducting carrying capacity studies provided by Shelby and Heberlein (1986), however, appear applicable to lake-based recreational settings. At the very least, their work provides a useful conceptual basis for planning carrying capacity studies.

3. Although boating "space standards" can be developed as part of carrying capacity studies for individual lakes, published standards should serve as only general guidelines for evaluating lake carrying capacity. Variable lake morphology and other factors precludes the development of uniform space standards.

4. A large amount of literature is available concerning the environmental affects of recreational activities on lakes. Although potential impacts have been identified, few studies have correlated user density (or intensity of use) to environmental impacts. Determination of ecological carrying capacity is ultimately a subjective decision.

5. Information is lacking concerning the magnitude of nutrient loading by recreationists into lake ecosystems. Particularly needed are studies to evaluate the effectiveness of regulations which prohibit the disposal of sanitary wastes into lake waters by boaters. It would be prudent to protect sensitive lakes by using pump-out vault type toilets (rather than septic systems), by taking measures to minimize improper waste discharges from boats (regulations and enforcement), and by minimizing shoreline erosion (i.e. limiting user density, proper site selection, shoreline restoration). Roughly 40 percent of New Hampshire lakes are oligotrophic (Estabrook, pers. commun.), and thus may be particularly vulnerable to nutrient enrichment.

6. Efforts should be made to restrict recreational activities in the vicinity of known loon nesting sites during the breeding and nesting season. Protection efforts may be important even ir. remote, relatively unused lakes where loons may be relatively sensitive to human disturbance.

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